Departments of Chemistry and Geology
The University of Wisconsin-Madison

# First Samples from the Moon

A few weeks ago, on TV, we watched our astronauts on the surface of the moon. That was exciting, but only the beginning of excitement for us. The Apollo 11 mission has brought to earth the first samples of rock known to have come here from the moon. Scientists at the Lunar Receiving Laboratory in Houston, Texas, have tested these rocks for biological and chemical safety. Now we, here at Wisconsin, are able to join them and others in making detailed studies of the materials. From these studies we hope to learn more about the origin and history of the moon and of the earth.

**What will we find?**

Several people have asked or guessed about what we hope to find.

New chemical elements? We believe that the physics and chemistry of matter are well enough understood that we cannot expect new elements. The earth and the meteorites are composed mostly of iron, oxygen, silicon, and magnesium. We suspect the moon is, too.

New minerals? The kind of minerals that form depend largely on the chemical elements that they are made of. Thus most of the moon probably consists of very familiar minerals. (In fact, olivine, feldspar, and pyroxene have already been identified by the scientists in Houston; these are very common on earth.) Minerals that could not survive in an atmosphere like the earth's may, however, be present.

Rocks wholly unlike what we see on earth? Rocks are aggregates of minerals. If lunar and terrestrial minerals are similar, then common lunar rocks probably resemble common terrestrial ones.

Thus, we expect that the most common lunar rocks will be pretty similar to some rocks we find on earth. What we don't know is just which rocks on earth they will resemble. And we expect them to be at least a little bit different from the terrestrial rocks they resemble most. By measuring these large similarities and small differences, we hope to understand better the origins and histories of both the moon and the earth. It is this hope that excites us. For all the expected similarities among their rocks, the moon and the earth are quite different places.

**Where did the moon come from?**

The very existence of the moon is a puzzle to earth-based scientists. As one suggests, it seems easier to show that the moon cannot exist, than to explain how it originated. Three of the most reasonable explanations and some of the problems with them are the following. All are consistent with the hypothesis that the sun, the planets, and other materials in the solar system accumuated from a huge cloud of dust and gas.

Theory 1. When the earth formed, the moon formed alongside it. The moon, however, is less dense than the earth. This probably means that the proportion of iron is lower in the moon than in the earth. No chemical separation in a cloud of dust and gas that could produce such a difference is know.

Theory 2. The moon was originally part of a rapidly rotating earth, and was spun off into an orbit around the earth, leaving the Pacific Ocean basin in its place. Mathematical examination shows that this process could not produce the present earth and moon without violating some of the best-established laws of physics (conservation of energy and angular momentum). More complicated variations of this theory are still being studied.

Theory 3. The moon formed far away from the earth, in a region where the proportion of iron was less, then was later captured by the earth. Just as the speed and direction must be precisely controlled for a spacecraft to go into earth orbit, so must the speed and direction of a moon be just right. It is thus hard to believe that a single moon coming into the vicinity of the earth could be captured by it without colliding and being destroyed.

An extension, or variation, of this theory is that the moon is one of the many similar objects prevalent in the primitive solar system. Most of these collided and were destroyed. The planets formed, in part, from their debris. Given enough moons, a few might have the necessary speeds and directions to be captured without destruction. If so, the moon is a more primitive body than the earth and represents an ancient step in the evolutionary history of the planets. Theory 3 appears to be the least objectionable and thus the most favored theory.

### The moon's structure

The surface of the moon consists of large, dark, relatively smooth areas called maria (seas) that are surrounded by lighter, mountainous highlands. Both are thickly dotted with craters. The names given to these features are borrowed from our descriptions of the earth. How similar, really, are these lunar and terrestrial features which bear the same names?

The seas on earth are filled with water, which is not found on the surface of the moon. There are smooth, dry plains on earth. These were once bottoms of seas that filled with material eroded from the surrounding highlands. There is little reason to believe that the lunar seas formed in the same way.

On earth, mountains occur in very specialized places. Their origin is not yet understood, but involves large-scale "wrinkling" of the earth's surface. Areas where new mountains are being built appear to be junctions between independent parts of the earth's crust. Geological and geophysical evidence suggest that the upper 75 miles or so of the earth's surface is made up of large slabs called crustal "plates." These slabs "float" on a very viscous, but fluid, region of the earth's interior. Where these plates are floating apart from each other, as along the center of the Atlantic Ocean, fresh material from deep within the earth rises to form volcanic mountains. Where crustal plates collide, one slides up, forming mountains and volcanoes, while the other is pressed down and returns its substance to the deeper portions of the earth. There is evidence that motion of these plates has been so extensive that the seven continents we now know are fragments of only one or two original ones that drifted apart. If lunar mountains had been formed this way, would not many of the older craters have been squeezed out of shape? They have not been.

What craters on earth resemble those on the moon? Most earth craters are volcanoes that have slumped and collapsed into their interiors. Some craters, for example Meteor crater in Arizona, were produced by objects falling from space. If the lunar craters are volcanic in origin, why are certain major surface features associated with terrestrial vulcanism absent? Actually, most lunar craters appear to be the collision type. If the lunar crater formed by impacts with meteorites, why is not the earth's surface similarly pitted? Of course, erosion and crustal movements on earth wipe out such craters in a fairly short time, and perhaps we have not yet learned how to detect their remnants. If such a bombardment of the earth had been steady throughout geologic time, however, how did our broad expanses of layered sedimentary rocks escape destruction? Perhaps most of the lunar craters were formed very early in the moon's history, before the crust of the earth was formed.

The large scale features of the moon's surface then, do not resemble closely those of the earth. The interior does not appear to be like the earth's either. The moon has no magnetic field. Its orbital motions do not indicate the presence of an iron core. On the side nearest the earth it has a bulge that should have sunk if the moon's interior were hot and fluid like the earth's.

Nevertheless, on a smaller scale, the moon does have features that resemble volcanic ash flows, gravity slumping, breached craters, small scale transport of material, and other structural characteristics we are familiar with here. The astronauts' description of the rocks was suggestive of volcanic rocks found on earth. The seismometer left on the moon has recorded several moonquakes, suggesting that motions do occur inside the moon, and that the moon, too, has a distinct crustal layer. To reconcile these discoveries with the appearance of the lunar surface and our present knowledge of the earth will require both careful examination of the moon rocks and more consideration of the processes that we think form similar rocks on earth.

### Mineralogy and bulk composition

We geologists* are interested in the lunar samples for what they can tell us about the mineral compositions of lunar rocks, and about the conditions and processes of rock formation on the moon. Our first task is to determine the minerals, or chemical compounds present, and their precise chemical compositions. The materials received will probably be in the form of polished sections cut from the lunar rocks. The sections will first be studied under the reflecting optical microscope,

*Eugene N. Cameron, Professor

and the number of different minerals present and their amounts will be determined. Some of the minerals should be identifiable directly under the microscope, from their optical and physical properties and comparison with known earth minerals. Some may require identification by x-ray diffraction methods, which give information on the atomic structures of minerals. Compositions of minerals will be further investigated by means of the electron microprobe housed in the Geology Department. By means of the microprobe, a tiny beam of electrons can be focused on any mineral grain in a polished section. The beam causes x-rays to be generated within the mineral, and these can be picked up by electronic scanning devices and their intensities measured. Each chemical element present in a mineral gives rise to characteristic wave-lengths of x-radiation. By determining what wave lengths are given off and measuring their intensities, the chemical elements present and their amounts can be determined. Mineral grains as small as 1/12,500th of an inch can be analyzed.

From the minerals present and their compositions, it should be possible to tell something of the temperatures and pressures under which the lunar materials have formed, because each mineral species forms only under a certain range of conditions.

Our second task is to examine the textures and structures of the lunar samples; i.e., the ways in which the minerals are bound together in the rocks. The preliminary reports suggest that there are igneous rocks in the collection brought back by Apollo 11; that is, rocks formed by crystallization of molten material. Their textures should tell us whether such materials formed deep within the moon or close to or at the surface. If there has been surface volcanic activity, the textures should tell us whether the eruptions have been quiet outpourings of lava or violently explosive events. What other processes of rock formation have operated on the moon no one really knows at present, but we should gain some knowledge of these from the mineral compositions and textures of the samples.

If the moon formed early in the history of the solar system, and has since been changed only locally by volcanic activity, rocks present on the moon could be of primitive kinds that on earth have long since been destroyed by complex processes of weathering, erosion, sedimentation, and mountain building that have been steadily at work for more than three and a half billion years. We have little knowledge of the original earth. Perhaps our studies of lunar samples from Apollo 11 and later missions will give us some insight into the nature and early history of our planet.

**Trace element analysis**

We chemists* will analyze bits of lunar rocks for trace, non-essential chemical elements. When a rock forms, its minerals are made from the most abundant elements. The parent material also contains tiny quantities of other chemical elements which must find a place for themselves in the rock. Some become trapped inside the structures of the minerals, others in cracks and along mineral grain boundaries. Every rock contains at least a tiny amount of every element. The quantity that is present tells something about the history of the rock that the mineral structure and bulk chemical composition do not.

Suppose, for example, that the rocks picked up by the astronauts contain as much of the trace elements barium, thorium, and lanthanum as similar terrestrial rocks. This would mean that material from deep within the moon had been extracted to form the lunar surface. In turn, this requires that the moon be hot inside. On the other hand, the amounts of those elements may be much lower than in the corresponding earth rocks. Then the lunar rocks probably formed from material already at the moon's surface, where collsion with a large meteorite caused local melting.

The ratio of the trace elements lanthanum and lutetium in certain volcanic rocks from the terrestrial continents averages about 75. The ratio for otherwise identical rocks from oceanic volcanoes is less than 10. We have not yet learned the reasons for this. Perhaps the composition of the parent rock material under the oceans is different from that under the continents. If there are volcanic rocks on the moon, will they more closely resemble our continental or our oceanic rocks? Does the moon represent an intermediate stage of chemical processing that the earth completed long ago?

*Larry A. Haskin, Professor; Ralph O. Allen, graduate student; Michael R. Anderson, James W. Blackbourn, and Kathleen A. Zweifel, undergraduates.

Trace element contents are often very low. For example, 100 tons of ordinary volcanic rock contain only 1/100 ounce of gold. To analyze for these elements by ordinary chemical means, we would first have to separate them from the major elements. This would require a large sample, and moon rocks are scarce. We would probably lose some of the element during the separation, and would not be able to correct for it. A slightly impure chemical used in the separations could add more of the trace element to the sample than was already in it. We would measure it just as if it belonged there.

To avoid these and other difficulties, we will analyze the rocks by neutron activation analysis. We first put the sample into the University's nuclear reactor (Nuclear Engineering Department). Neutrons react with the major and trace elements in the rock to produce radioactive isotopes of them. Each isotope, when it decays, emits a gamma ray with a characteristic energy. These gamma rays are trapped in a crystal of germanium, which gives off an electrical signal for each. By electronic analysis of these signals, a "multichannel radiation analyzer" determines the number of gamma rays emitted by each different isotope. The number of gamma rays from a particular isotope tells how much of that isotope was formed in the reactor. That tells, in turn, how much of the parent element was in the sample.

Chemicals are used on the sample only after the neutron irradiation, so their impurities don't give off gamma rays. Unknown losses during separations can be avoided. And the technique is so sensitive that only 1/100 ounce of sample is required for analysis of more than 30 trace elements.

**A note of caution**

These studies will teach us much more about the moon than we now know, but they will leave unsolved many questions about how the moon's features formed. For one thing, these samples are only from the surface of the moon, and only from one very small area. Geologists using Lunar Orbiter photos find there may be several classes of surface materials. Careful scrutiny by experienced geologists on the lunar surface will be required for any detailed understanding. After all, we don't yet understand many features of the earth's crust in spite of considerable effort and easier access.